Historic, archived document

Do not assume content reflects current
scientific knowledge, policies, or practices.

84C

3

Circular No. 835

Grain Bin Requirements

By Benton M. Stahl, *agricultural engineer, Division of Farm Buildings and Rural Housing, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration.*[1]

CONTENTS

INTRODUCTION

In recent years a great amount of grain has been held in comparatively small storages, either on farms as collateral for loans or on community sites supervised by Government agencies handling surplus production. Investigations of the hazards and service demands pe-

---

[1] This circular is based on studies of wheat storage in cooperation with the Kansas, Iowa, and North Dakota Agricultural Experiment Stations. Space does not permit a complete list of everyone who offered helpful criticisms and suggestions in its preparation. The group included members of the Farm Structures Institute, farm building specialists in the agricultural colleges, officials in charge of Government grain-storage programs, entomologists, and others conducting research on grain-storage problems. In preparing the charts special assistance was given by E. G. Molander, senior agricultural engineer, Division of Farm Buildings and Rural Housing, Bureau of Plant Industry, Soils, and Agricultural Engineering, and by N. H. Curry, research associate professor of agricultural engineering, Iowa State College.

culiar to this type of grain storage were therefore necessary and possible. The results of several investigations that showed the dominant effect of time, temperature, and moisture on the deterioration of stored grain have been published (*6, 14, 20, 21, 22*).[2] Experience has shown that many storages having one or several excellent features give inadequate service because other equally important features of design or use have received too little attention. No attempt will be made here to describe these details of construction. Other publications giving such information are available (*8, 10a, 12, 15, 16, 18, 21a, 23, 27, 28*).

The use of new materials and new methods of fabrication can be expected. New structural features will be required to permit more effective and widespread use of grain-conditioning equipment and insect fumigants. Valuable information may be obtained from existing designs, but a more productive guide to better storage designs should be found in a reasonably complete statement of the functions of a storage and the environmental conditions that may affect these functions. If the material in this publication is used as such a guide, or check list, and each of the requirements is considered carefully, there should be small risk of an unsatisfactory storage design or investment.

FUNCTIONS OF A GRAIN STORAGE

The conservation of grain after harvest may be divided into three different operations: Handling, conditioning, and storage. Successful performance of the equipment needed in these operations depends on proper management as well as on good functional design. For example, a grain storage cannot be designed to relieve the user of all responsibility for grain deterioration and loss or for hazardous and inconvenient working conditions.

The following discussion is limited to the functions of storages for threshed grain and shelled corn. Two general functions, providing for the greatest practicable safety and providing for convenience in handling, conditioning, and storing, affect the design of these structures. The storage should help to:

1. Keep the grain safe from—
(*a*) Damage due to moisture.
(*b*) Damage due to heat.
(*c*) Damage by insects.
(*d*) Loss in quantity.
(*e*) Objectionable odors and materials.
2. Provide job-safety and convenience when—
(*a*) Moving grain (to, into, out of, and from the storage).
(*b*) Inspecting the grain.
(*c*) Servicing the grain and storage.

An explanation of each phase of these two functions is given to clarify subsequent statements of structural requirements.

1 (*a*). *Damage due to moisture.*—In a bulk of dry grain the development of serious damage due to moisture is generally localized, being limited to those portions that are or become relatively damp. When the storage is being filled, small amounts of damp grain or foreign material such as weed seeds and chaff (*4*) may not be detected. These portions frequently tend to accumulate directly below the point of entry unless they are well distributed by a movable spout, deflector,

---

[2] Italic numbers in parentheses refer to Literature Cited, p. 11.

or similar device. Such accumulations provide a favorable environment for mold and insect activity.

All grain in storage contains moisture that can be shifted from one to another part of the bulk. This disturbance of the bulk moisture condition is due primarily to temperature differences that develop within the mass of grain. These differences cause convection movements in the entrapped air. Moisture given up by the warm grain is transferred to cooler parts of the bulk that may accumulate sufficient moisture to become relatively damp. These damp places favor mold and insect activity and rapid deterioration of the moist grain.

Moisture hazards in bulks of dry grain become worse if additional water enters the storage. Water that leaks through the roof or walls causes damage to grain at or near the floor and walls. This damage is difficult to detect until the storage is emptied, unless rather large amounts of grain are spoiled. Accumulations of snow or ice on the roof or against the walls of the storage do not melt uniformly. Water draining from the melting part may be obstructed and penetrate overlapping joints and flashing. Snow that blows into the storage tends to accumulate where the velocity of entering air is reduced. Surface and subsurface grain under these snow deposits will become damp or wet if the snow is not removed before it melts.

Soil moisture and floodwater may penetrate the floor material or joints. When this penetration occurs it leads to spoilage of the bottom part of the bulk.

Moisture from damp outdoor air is usually limited to the top-surface grain in unventilated bulks. Moisture equilibrium is quickly established in this layer of grain. A similar condition in grain 1 inch below this surface may result only from continuous exposure to damp air for 1 to 2 weeks.

Small portions of a bulk may be wetted by condensed moisture that drips or drains from roof, wall, or air-duct surfaces at dew-point temperatures. But free water (dew) does not occur on structural surfaces in contact with dry grain during typical variations in outdoor temperatures. A saturated condition of the entrapped air at such surfaces is prevented by the absorbent action of the grain.

1 (b). Damage due to heat.—Heat damage usually results from the daily and seasonal variation in bulk temperatures (*25*). As heat is gained and lost by the bulk of grain, a wide range of temperatures occurs that may include optimums for deterioration and the destructive activity of micro-organisms and insects. Furthermore, when large differences in temperature develop within the bulk, some of the grain may become damp enough to undergo very rapid deterioration. To reduce these risks the bulk temperatures must be maintained as uniform and low as the storage locality permits.

Heat gains due to respiration of the grain (*26*), micro-organisms, and insects are insignificant unless much of the grain is or becomes damp or heavily infested with insects. When these conditions occur, they should be corrected by appropriate treatment.

Heat gains and losses by conduction during daily and seasonal changes in outdoor-air temperatures may be retarded. The average annual bulk temperature will not be changed, but bulk temperatures will be more uniform, and there will be less transfer of heat and moisture by convection.

Heat gains from solar radiation may be reduced. Bulk-temperature

differences will not be changed, but the average annual bulk temperature will be lowered. Heat losses by negative radiation (*10*) may be increased and, with effective reduction of solar-heat gains, the average annual bulk temperature may be lowered as much as 10° F., a temperature drop that would reduce the rate of deterioration of grain to half the rate at the higher temperature (*26*).

Heat gains and losses due to outside-air penetration or infiltration are negligible in an unventilated bulk except in the upper exposed portion. However, by adequate cross-ventilation of the space above the top surface of the bulk, a large part of the solar-heat gain that passes through the roof can be carried off. But if solar heat is reflected by and does not pass through the roof, the top surface of the bulk will remain cooler without cross ventilation.

1 (c). Damage by insects.—The damage done by heavy infestations of stored-grain pests is not limited to their feeding on sound kernels. Another type of damage results from their tendency to concentrate in those portions of a bulk where moisture and temperature conditions are most favorable for them. In the grain surrounding such centers of activity, moisture and temperature gradients are soon established (*29*). These gradients usually include conditions that promote damage to the grain by micro-organisms and fermentation processes. In northern localities this type of damage may develop quickly, especially in bulks containing accumulations of broken kernels or foreign material such as grain dust, when large numbers of insects congregate below the cold surface layers of grain. A less common type of damage is the offensive, commercially objectionable insect odor that grain acquires from some of these pests (*2*).

By prompt detection of infestation and application of enough fumigant, serious damage can be prevented. The cost of this treatment and its repetition or the damage that otherwise develops is often the result of faults in the storage structure.

Wood members in which insects may burrow and ledges, crevices, pockets, or similar places where old grain or grain particles and dust may accumulate provide hiding and breeding places for insects that infest new grain. Or grain that has been fumigated may be reinfested by stored-grain insects that crawl or fly through joints or other openings in the structure. Leakage of fumigant vapor may prevent extermination of all stages of insect life unless heavier than normal dosages are used. Otherwise, repeated applications of fumigants are necessary to check the rapid multiplication of surviving insects.

1 (d). Loss in quantity.—Prevention of loss in quantity is generally recognized as the primary function of a storage. Stored grain may be lost in many ways. It may be removed by trespassers or consumed by rodents, birds, and livestock or may be destroyed by fire or washed away by flood. Some of the grain will be lost in any salvage process. Structural defects or weaknesses may result in spilling, slow leakage, or sudden dumping of grain that cannot be completely recovered.

Losses due to fire, flood, and theft can usually be prevented by locating a storage where these hazards are negligible. Therefore, special protection from such losses is not considered a normal or characteristic function of a grain storage. Storages in a condition or location in which dust-explosion hazards exist should be given special protection other than that which is required for saving grain (*5*).

4

1 (e). Objectionable odors and materials.—The United States Department of Agriculture official grain standards provide that grain shall be graded as "sample grade" if (1) it has a musty, sour, or any commercially objectionable odor, (2) it contains inseparable stones or cinders, or both, or (3) it is otherwise of distinctly low quality. In addition to losing much of its market value, such grain may also become unpalatable and even dangerous as feed.

The principal sources of objectionable odors are the following: Mold growth, fermentation, insects, birds, rodents, manure, some fertilizers, gasoline, kerosene, and creosote. Objectionable materials, other than inseparable stones and cinders, include the following: Nails and similar sharp objects, poisonous chemical dusts, and excreta from birds, rodents, and livestock.

2 (a). Moving grain (to, into, out of, and from the storage).—Securing the greatest safety and convenience in hauling grain to and from the storage generally requires consideration of the storage location with relation to field or road conditions and the purpose for which the grain is saved, for example, seed, feed, or market. Structural features of the storage also need consideration. Thus, the location may introduce special storage hazards such as easier theft by trespassers and greater risk of flood or fire. Unless the storage structure provides adequate protection from such hazards, the advantage of the location for hauling grain may be lost.

In the design of small granaries and bins there is a tendency to overlook the importance of the various structural features that are involved in filling and emptying the storage (*15, 11*). As a result, the use of equipment for moving and controlling the flow of grain, such as shovels, portable or stationary conveyors, spouts and gates, may be difficult or dangerous. These possibilities should be considered in determining the location and size of necessary openings, the position of cross ties and air ducts, and the provision of such items as ladders, cleats, and guardrails.

2 (b). Inspecting the grain.—A common cause of unsuccessful grain storage on farms is inadequate inspection (*10a, 27*). Thus, an insect infestation or the presence of damp or heating grain may not be detected and treated before extensive damage develops. At other times expensive treatments, such as fumigating or transferring the grain, are applied when not required. For a satisfactory inspection when the storage is normally full there must be enough headroom to permit examination of the entire surface layer of grain. This headroom should also be sufficient to allow convenient use of a grain probe in securing samples from any portion of the bulk. Suitably located roof hatches, wall ports, or other openings should be provided where the amount of headroom is limited.

2 (c). Servicing the grain and storage.—Keeping grain in good condition may require, in addition to inspection and fumigation, other services that are generally neglected if they cannot be performed conveniently and safely. A common example is the need for drying any portion of a bulk that becomes damp. If this damp portion cannot be withdrawn or shoveled from the storage it will be necessary to transfer the entire bulk to available drying facilities. Such facilities may consist of a bin equipped for artificial drying or a sheltered floor where grain can be spread in a thin layer. Similar servicing may be required when any

5

portion of a bulk is found to be heating. A storage for seed grain should be designed to permit convenient use of cleaning and seed-treating equipment. Feed-storage structures should have features that reduce the labor required to regulate the flow of grain and its transfer to equipment for hauling, weighing, grinding, and mixing.

In the operation and maintenance of a storage the structural design, materials, and environment affect the convenience and frequency of servicing. Examples of adverse factors include weak foundations, easily deformed materials for doors, and locations where termites, corrosion from smoke, and the vibration of heavy traffic are serious. Structural features, such as those for controlling aeration and the flow of grain, may be so inconvenient to operate and repair that they are damaged and remain in poor condition. Necessary servicing may also be neglected when materials that will rust or rot are so fabricated that these conditions can develop without being easily detected.

STRUCTURAL REQUIREMENTS

FOUNDATIONS

Except for the heavy loads imposed by grain the same conditions that determine foundation requirements for other farm structures apply to grain bins. In design calculations (*18*) the unit weights given in table 1, Appendix, should be considered as minimum live-load values.

ANCHORING

All parts of the anchoring system (fastenings to bin and ground or foundation and the connecting members between these fastenings) must have sufficient strength and be installed so as to prevent any shifting or lifting of the empty bin by impact of wind, grain-handling equipment, or livestock.

Anchoring systems should not interfere with or be exposed to damage by farm equipment or livestock. For portable bins the anchoring should be easily installed and disconnected. Such anchoring may also be required for temporary emergency bins if they cannot be filled immediately after erection.

In calculating the overturning moment due to wind, which must be resisted by the anchoring system of portable or similar lightweight bins, the following unit pressures per square foot of projected area are recommended: 24 pounds for bins 10 feet high, 27 pounds for bins 15 feet high, and 29 pounds for bins 20 feet high. When these values are used in calculating the overturning moment, an equivalent resisting moment should be safe for all but the most extreme winds. Greater design pressures have been recommended for barns (*9, 19*) and may be advisable for granaries of comparable size and shape.

FLOORS

Structural features should prevent water from penetrating to any part of the floor that contacts grain. Particular attention to the design of joints between the floor and outside walls is required (*24, 27*). If the bin must be located where surface and soil-water drainage do not protect the subfloor from occasional wetting or continued dampness,

the finish or subfloor, or both, should include materials that prevent the penetration of water vapor or capillary moisture.

The construction should be tight enough to prevent excessive leakage of fumigant vapors. If a floor of perforated metal or similar material is used, the design should permit convenient and effective sealing of the space beneath the floor. Easy and complete removal of old grain and foreign material that may harbor stored-grain insects should be possible. Structural details or fabricated materials that introduce obstructions, cracks, or pockets at the floor surface should be avoided if practicable. This is particularly important when the bin has a self-cleaning hopper bottom. Floors of this type will not give satisfactory service if the slope is less than the emptying angle of repose of the grain that is stored (table 2, Appendix). Ordinarily a slope 10° greater than these angles of repose is needed to assure removal of small particles such as broken kernels and grain dust. If damp grain must be handled, the walls of the self-cleaning hopper will require a slope 25° greater than the angle of repose for clean and dry grain.

In estimating the strength required to prevent loss of grain the average unit pressures given in chart (fig. 2, A, Appendix) are recommended. These average pressures represent a load increasing uniformly to the center of the floor (15) producing a bending moment represented by the formula $M = 1/6\ Wl$, where M is the bending moment, W the total load, and l the span. Flooring near doors and corners may be subjected to impact, abrasion, and tearing by shovels and grain-conveying equipment. Protection from or resistance to such damage should be provided. Similarly the floor should be resistant to or protected from gnawing by rodents (23) or damage by termites (28) and cadelle beetles (3). Structural features or material treatments that will prevent the loss of necessary strength and tightness due to wood rot, metal rust, or disintegration of masonry should be used, especially in permanent storages. However, flooring that contacts grain should not be treated with materials such as creosote, which give grain commercially objectionable foreign odors.

WALLS

Exterior wall materials and joints should exclude draining water and rain or snow blown from any direction. If these walls include members such as exterior stay timbers or door frames, where snow or water may accumulate, they should be flashed. Materials used for calking or gaskets frequently fail to give permanent protection (24).

Exterior walls should be protected from solar heat. Such protection will retard or prevent the development of damage in bulk grain (1 (b), p. 3) and possible damage to the wall from overloading. (See below.) White or other reflective surfaces or shading, or both, are generally most practicable for this purpose. If insulation is used to eliminate daily fluctuations in grain temperature, it should have a thermal conductance equivalent to that of a layer of wheat at least 12 inches thick, that is, approximately 0.08 British thermal units per square foot per hour per degree difference in temperature (26).

All walls should be tight enough to prevent excessive leakage of fumigant vapors. Any of the common types of wall, except perforated metal, will meet this requirement if kept in good repair. All parts of the wall should be self-cleaning to assure removal of old grain that might harbor insects. Many farm storages, especially multiple-bin

granaries of wood construction, do not have this desirable aid to sanitation. Designs should include beveled surfaces wherever needed on bracing, cross ties, interior stay timbers, sills and plates; and the shielding or preferably the elimination of inaccessible pockets formed by the wall assembly.

For general use in estimating strength requirements the maximum wall loads given in charts (figs. 1, *A* and *B*; 2, *B*; and 3, Appendix) are recommended. These allow for ordinary changes in pressure such as those that may occur during filling and emptying (*15*), and those due to characteristic reactions of different kinds of grain (*26*). For example, shelled corn has a much higher thermal conductivity and lower resistance to air flow than wheat (*26*). The coefficient of thermal expansion of wheat is not known, but for dry (9.3 percent moisture wet basis) shelled corn it is 0.187×10^{-4} per ° F., which is about 3 times that for steel (0.0608×10^{-4} per ° F). In corrugated steel bins of identical size and construction those used for wheat have shown no evidence of overloading but many of those used for corn have crippled walls where lighter gage sheets have very gradually folded down on heavier gage supporting sheets. This deformation always begins on the wall receiving the most solar radiation and is often limited to it. Protection from possible damage by trucks or other grain-handling equipment may be necessary if walls are made of easily punctured materials. Possible deformation or collapse of stave-type walls because of eccentric filling and emptying requires consideration in the design of deep bins (*15*) but is relatively unimportant in shallow bins (*1*) that are slowly filled and emptied.

For bins that require the use of cross ties and cannot be completely emptied without shoveling, the maximum amount of headroom consistent with structural efficiency should be provided. A clearance of at least 5 feet between floor and tie is desirable. But a clearance of 4 feet is suggested as a permissible minimum, especially in bins of small capacity (less than 1,000 bushels).

Roofs

All roof joints should exclude draining or standing water (on either flat or steep roofs) and blowing rain or snow. In localities (*17*) where fine dry snow is a common hazard, the joints at eaves should be of dust-tight construction or be easily sealed to give equivalent protection. Condensation on the underside of roofs (*10*) is insufficient to cause damage when bins are filled with grain that is in suitable condition for safe storage.

The roofs of outdoor bins should be protected from solar heat by white or other reflective surfaces or shading, or both. Such protection provides a more comfortable space for workmen without the use of ventilators (*1* (*b*), p. 4). It also retards insect infestations by keeping the surface layers of grain cooler.

Many flying or crawling stored-grain insects can pass through very small openings. Roof joints, especially at the eaves, should be tight enough to prevent this. Such construction will also help prevent the dissipation of fumigant vapors during windy weather. Any framing that extends under filling hatches or discharge spouts should have self-cleaning surfaces.

When bins are located under a floor where objectionable materials,

such as poisonous dusts or fertilizers, may be stored, the floor should be of dust-tight construction.

Any part of the roof that must be used as a deck should have strength to support the following loads without permanent deformation of framing and opening of joints or fracture of the deck surface: Either 300 pounds concentrated at center or 30 pounds uniform, whichever is greater for the spans involved. When the roof is more than 10 feet above the ground, safeguards against injury by slipping and falling, such as cleats or handrails, should be installed.

Headroom should not be less than 2½ feet at a distance of 3 feet from any wall. This headroom will permit reasonably convenient inspection of all surface grain and probing of any portion of the bulk to a depth of 4 to 5 feet. Ordinarily this will be sufficient for determining the need for fumigation (*7, 27*) or for examining grain that may become too damp as a result of moisture migration (*25*). Bin-capacity ratings should be based on this minimum headroom requirement. However, design loads should allow for possible filling of the bin to the eaves.

Openings, Ducts, and Closures

The openings, ducts, and closures of the structure often fail to exclude draining or standing water and blowing rain or snow. Inadequate flashing, defective joints, and deformation at the edges of openings and closures are common faults. Doors or hatch covers that do not fit properly may have to be pried open or hammered shut. Materials are often used without necessary protection or reinforcing to prevent warping and swelling or bending and buckling. Louvres in gable or ridge ventilators and ventilating cowls fail to function during severe storms or blizzards (*13*). Wall openings for air ducts may not be closed before such weather occurs.

Air ducts may be used to keep bulk temperatures more uniform (*1* (*b*), p. 3). But the risk of damage from condensation on the inner surface of the ducts (*1* (*a*), p. 3) may be too great to justify their use unless the design of duct joints, perforations, or inner surfaces provides positive protection against wetting of the grain by penetration or drainage of the condensate. Duct-wall and air temperatures differ as much as 10° to 20° F. during daily changes in outdoor temperature (*25*).

All ducts or spouts and the framework for openings should be easy to clean or self-cleaning. (See section on Floors, p. 6, for reference to required slopes.) To prevent the entrance of stored-grain insects all openings should be screened or have closures that give equivalent protection. A 24-mesh screen (Tyler Scale) will exclude all of the more important species except the lesser grain borer and the saw-toothed grain beetle. A 32-mesh screen should be used for storages located in regions (3 and 4) where insect control is most difficult (*7, 27*). This small-mesh screening will have some adverse effect on air flow and the use of ventilated bins in these regions should be restricted. (See special requirements for ventilated bins, p. 11.) All openings and closures in walls or floor that must be made vaportight before fumigation should permit easy and effective application of sealing tape, calking, or other temporary aids.

Slow leakage of grain from defective joints in either the framing or the closure of wall and floor openings may not be noticed until a large

quantity of grain has been consumed by rodents, birds, or livestock. The location and size of openings for filling a bin by shoveling from wagons or trucks may result in excessive spilling and waste of grain. Whenever practicable such openings should have no dimension less than 2 feet and the bottom edge should not be more than 8 feet above the ground. A minimum dimension of 1½ feet and 10 feet above ground may be considered as permissible limits. Scoop doors in exterior walls should prevent the flow of grain over the edge of the floor. Because of the dragging action of a shovel the grain tends to assume the filling angle of repose (table 2, Appendix). This angle should be used in determining the position of the bottom grain board in these doors. The same requirement applies in preventing excessive spilling of grain from wall ports during probing. Closures for openings and spouts discharging grain to elevating equipment or to containers such as sacks should operate easily and effectively. Failure of these devices to regulate or stop the flow of grain quickly is a common fault in farm storages. To estimate the rate of flow through horizontal (floor) discharge openings (*26*) the following equations can be used: $Q = 0.1753 D^3$ or $Q = 0.2232 W (WL)$ where $Q =$ bushels per minute, and D, W, $L =$ diameter, width, and length of opening in inches, respectively. For vertical (wall) openings the rate of flow will be ⅓ Q.

If air ducts are located in a position that interferes with the removal of grain by ordinary equipment they should be easily removable when free from surrounding grain. Any opening that must be used as a manhole should be at least 2 feet in diameter, or 1½ feet wide if more than 2 feet long. The manhole must be accessible to men working in the bin, especially when the bin is only partially filled. Failure to meet this requirement makes the bin a serious hazard. Workmen may become ill or injured while inspecting, fumigating, or shoveling grain. If access is provided by a wall ladder it should extend from the manhole to the grain-discharge opening. If this is not practicable (for example, if the manhole is located in the top of a dome roof), a rope ladder should be considered an essential part of the structure.

SPECIAL REQUIREMENTS

The service required of bins erected for temporary or emergency storage is generally rather limited. They must not permit water to penetrate to the grain and must be sufficiently strong and tight to retain the grain. Resistance to damage by hail, rodents, and livestock may be necessary. Low-cost rather than very durable materials are preferable if they meet the above requirements. Construction features that permit the greatest ease and speed of assembly are desirable. If expensive or permanent materials are used, the construction features should permit recovery of the greatest possible salvage value.

Portable bins for semipermanent locations should meet all of the requirements that have been given for permanent storages. Materials and construction of the lightest weight that will meet these requirements should be used. If this is not possible, the bin dimensions should be reduced and additional units built to meet the required storage capacity. Construction features to resist wind damage when the bin is empty, or racking when it is being moved, are essential. Particular attention must be given to the anchorage system for this type of bin.

Bins that are desired for other uses besides grain storage should have

10

window and door framing adapted to the installation of baffle boards or other removable closures. All requirements for safe storage should be provided. If grain storage will probably be a minor service demand, it may be uneconomical to provide sufficient strength to permit filling the bin with grain to the eaves. Safe filling depths should be clearly indicated on bin walls when necessary.

Ventilated bins for the safe storage of grain that must be dried or cooled, or both, should be limited to use in relatively dry or cool climates. The grain should be clean and not too damp (*14, 22, 17*). Particular attention should be given to structural means for excluding rain and snow. In construction consideration must be given to insect control, including effective fumigation. The fine-mesh screen requirements previously mentioned may so retard the flow of air that naturally ventilated bins cannot be successfully used for drying grain. But such screening will not seriously interfere with the effectiveness of ventilators and air ducts as a means for dissipating heat from bulks of grain. Structural features to permit sufficient air flow (*26*) through all portions of the bulk at ordinary wind velocities must be used if effective drying of grain is desired. The design of these features should also permit moving and inspecting the grain and servicing the grain and storage (*2 (a)*, *2 (b)*, and *2 (c)*, p. 5).

The size and proportions of a bulk may introduce special problems and requirements other than those due to grain pressures. In bulks of equal volume, insect control will be more difficult and heavier doses of fumigant will be necessary in those that are relatively shallow. Such bulks have a greater surface exposed to insects such as the Angoumois grain moth and the Indian-meal moth. Special features may be needed to get uniform distribution of fumigants over the larger surface area. Relatively deep bulks, especially in bins with walls exposed to the sun, tend to develop greater subsurface concentrations of moisture than do shallow bulks.

LITERATURE CITED

(1) Amundson, L. R.
   1945. determination of band stresses and lateral wheat pressures for a cylindrical grain bin. Agr. Engin. 26 : 321–324, illus.
(2) Back, E. A., and Cotton, R. T.
   1922. stored-grain pests. U. S. Dept. Agr. Farmers' Bul. 1260, 46 pp., illus. (Revised, 1940)
(3) ——— and Cotton, R. T.
   1926. the cadelle. U. S. Dept. Agr. Dept. Bul. 1428, 42 pp., illus.
(4) Black, R. H., and Boerner, E. G.
   1927. cleaning grain on farms and in country elevators. U. S. Dept. Agr. Farmers' Bul. 1542, 27 pp., illus.
(5) Brown, H. R., and Reed, J. O.
   1926. dust control in grain elevators. U. S. Dept. Agr. Dept. Bul. 1373, 43 pp., illus. (Revised, 1928)
(6) Carter, E. P., and Young, G. Y.
   1945. effect of moisture content, temperature, and length of storage on the development of "sick" wheat in sealed containers. Cereal Chem. 22 : 418–428.
(7) Cotton, R. T.
   1938. control of insects attacking grain in farm storage. U. S. Dept. Agr. Farmers' Bul. 1811, 14 pp., illus.
(8) Edgar, A. D., and Miller, T. A. H.
   1935. roof coverings for farm buildings and their repair. U. S. Dept. Agr. Farmers' Bul. 1751, 30 pp., illus. (Revised, 1948.)

(9) FENTON, F. C., and OTIS, C. K.
    1941. THE DESIGN OF BARNS TO WITHSTAND WIND LOADS. Kansas Engin. Expt. Sta. Bul. 42, 76 pp., illus.

(10) HENDERSON, S. M.
    1947. NEGATIVE RADIATION—ITS RELATION TO FARM BUILDING DESIGN. Agr. Engin. 28: [137]–140, illus.

(10a) HOLMAN, L. E., BARRE, H. J., COTTON, R. T., and WALKDEN, H. H.
    1949. STORAGE OF DRY SHELLED CORN IN FARM-TYPE BINS. U. S. Dept. Agr. Cir. 826, 36 pp., illus.

(11) HUDSON, W. G.
    1949. CONVEYORS AND RELATED EQUIPMENT. 468 pp., illus., New York.

(12) KELLEY, M. A. R., and BOERNER, E. G.
    1930. FARM BULK STORAGE FOR SMALL GRAINS. U. S. Dept. Agr. Farmers' Bul. 1636, 45 pp., illus. (Revised, 1940.)

(13) KELLY, C. F., CROPSEY, M. G., and SWANSON, W. R.
    1942. PERFORMANCE OF COWLS FOR VENTILATED GRAIN BINS. Agr. Engin. 23: 149–151, illus.

(14) —— STAHL, B. M., SALMON, S. C., and BLACK, R. H.
    1942. WHEAT STORAGE IN EXPERIMENTAL FARM-TYPE BINS. U. S. Dept. Agr. Cir. 637, 245 pp., illus.

(15) KETCHUM, M. S.
    1919. THE DESIGN OF WALLS, BINS AND GRAIN ELEVATORS. 566 pp., illus. New York. (Reprinted, 1929.)

(16) KRAMER, H. A.
    1944. FACTORS INFLUENCING THE DESIGN OF BULK STORAGE BINS FOR ROUGH RICE. Agr. Engin. 25: 463–466, illus.

(17) LONG, T. E., and CROPSEY, M. G.
    1941. GRAIN STORAGE ON THE FARM. N. Dak. Agr. Expt. Sta. Bul. 302, 68 pp., illus.

(18) MILLER, T. A. H., and MOLANDER, E. G.
    1941. FOUNDATIONS FOR FARM BUILDINGS. U. S. Dept. Agr. Farmers' Bul. 1869, 44 pp., illus.

(19) MOLANDER, E. G.
    1947. WIND LOADS ON FARM BUILDINGS. Agr. Engin. 28: 22–24, illus.

(20) RAMSTAD, P. E., and GEDDES, W. F.
    1942. THE RESPIRATION AND STORAGE BEHAVIOR OF SOYBEANS. Minn. Agr. Expt. Sta. Tech. Bul. 156, 54 pp., illus.

(21) SEMENIUK, G., NAGEL, C. M., and GILMAN, J. C.
    1947. OBSERVATIONS ON MOLD DEVELOPMENT AND ON DETERIORATION IN STORED YELLOW DENT SHELLED CORN. Iowa Agr. Expt. Sta. Res. Bul. 349, 1947: [253]–284, illus.

(21a) SHEDD, C. K.
    1949. STORAGE OF EAR CORN ON THE FARM. U. S. Dept. Agr. Farmers' Bul. 2010, 27 pp., illus.

(22) —— and WALKDEN, H. H.
    1947. GRAIN SORGHUM STORAGE. U. S. Dept. Agr. Cir. 760, 48 pp., illus.

(23) SILVER, J., CROUCH, W. E., and BETTS, M. C.
    1942. RAT PROOFING BUILDINGS AND PREMISES. U. S. Dept. Int. Conserv. Bul. 19, 26 pp., illus.

(24) STAHL, B. M.
    1946. STORAGE PERFORMANCE OF GRAIN BIN FLOORS. Agr. Engin. 27: 357–362, illus.

(25) ——
    1947. FACTS ABOUT STORED GRAIN. Amer. Feed and Grain Dealer 31: 14–16, 44, illus.

(26) ——
    1948. ENGINEERING DATA ON GRAIN STORAGE. Agr. Engin. Data 1: 1–11, illus.

(27) UNITED STATES DEPARTMENT OF AGRICULTURE
    1949. STORAGE OF SMALL GRAINS AND SHELLED CORN ON THE FARM. U. S. Dept. Agr. Farmers' Bul. 2009, 30 pp., illus.

(28) UNITED STATES DEPARTMENT OF AGRICULTURE
    1942. PREVENTING DAMAGE TO BUILDINGS BY SUBTERRANEAN TERMITES AND THEIR CONTROL. U. S. Dept. Agr. Farmers' Bul. 1911, 37 pp., illus. (Revised, 1946.)

(29) WILSON, F.
    1946. INTERACTION OF INSECT INFESTATION, TEMPERATURE, AND MOISTURE CONTENT IN BULK-DEPOT WHEAT. Austral. Council Sci. and Indus. Res. Bul. 209, 31 pp., illus.

APPENDIX

TABLE 1.—*Maximum weights of various grains* [1] *ordinarily found in commerce* [2]

Grain	Test weight per bushel	Per cubic foot
	Pounds	*Pounds*
Wheat:		
Hard red spring	65	52. 0
Durum	65	52. 0
Hard red winter	64	51. 2
Soft red winter	61	48. 8
White	61	48. 8
Corn, shelled	60	48. 0
Soybeans	58	46. 4
Grain sorghums	58	46. 4
Rye	58	46. 4
Flaxseed	54	43. 2
Barley:		
Western	54	43. 2
Eastern	50	40. 0
Rough rice, American Pearl [3]	52	41. 6
Oats:		
Pacific Northwest and Canada	44	35. 2
Central United States	42	33. 6

[1] Small lots of exceptionally heavy wheat (55 pounds per cubic foot) are sometimes found in exhibits but do not represent lots of commercial size. In storages for ear corn a unit weight of 35 pounds per cubic foot can be used as a probable maximum. To determine the maximum loads shown in charts (figs. 1, *A* and *B*, and 2, *A* and *B*, 3, and 4) the weight of exceptionally heavy wheat has been used in Janssen's formula (15). By assuming values of *K* (ratio of lateral to vertical pressures of grain) and known values of *u'* (coefficient of friction of grain on bin wall) the resulting loads can be considered as equal to or greater than those produced by any kind of grain.

[2] Data furnished by H. P. English, Grain Branch, Production and Marketing Administration.

[3] Data furnished by W. D. Smith, Grain Branch, Production and Marketing Administration.

Grain	Angles of repose		Average coefficients of friction of grain on [2]—					
	Emptying or funneling	Filling or piling	Smooth shiny tin	Smooth side Prestwood [3]	Across grain of plywood	Wall boards		
						Rough side asbestos cement	Gypsum	Insulite [3]
	Deg.	*Deg.*						
Rough rice (paddy)	36	20	0.479	0.554	0.530	0.368	0.637	0.662
Grain sorghum	33	20	.372	.306	.294	.331	.396	.321
Oats	32	18	.445	.398	.380	.362	.442	.429
Soybeans	29	16	.368	.295	.312	.301	.379	.306
Barley:								
Two row	28	16	.404	.264	.311	.308	.389	.360
Six row	28	16	.378	.266	.287	.298	.344	.354
Wheat:								
Hard red spring	28	17	.366	.335	.298	.333	.394	.325
Hard red winter	27	16	.340	.306	.294	.323	.392	.287
Soft red winter	27	16	.356	.306	.277	.292	.372	.300
Corn	27	16	.447	.306	.302	.264	.416	.257
Wheat, Durum	26	17	.414	.321	.321	.323	.418	.311
Rye	26	17	.406	.324	.330	.354	.398	.350
Flaxseed	25	14	.372	.300	.275	.323	.319	.350
Vetch	25	14	.327	.255	.249	.242	.340	.270

[1] Results of tests made in Grain Storage Laboratory, Ames, Iowa.
[2] For coefficients of friction of grain on other materials see Ketchum (*15*) and Stahl (*26*).
[3] Mention of these brands should not be construed as an endorsement by the Department of Agriculture of either the prices or quality of these products. No discrimination is intended and no preference can be expressed or implied.

EXAMPLES OF USE OF CHARTS

NOTE.—The loads shown for cylindrical grain bins also apply to rectangular bins of equivalent diameters. The equivalent diameter of a bin equals 4 times the hydraulic radius, that is, $4\left(\dfrac{\text{floor area}}{\text{floor perimeter}}\right)$. Thus a bin 6 feet wide and 12 feet long has an equivalent diameter of $4\left(\dfrac{72}{36}\right)=8$ feet. A chart showing equivalent diameters of rectangular bins is given by Stahl (*26*).

Problem 1.—For a bin with wall height 10 feet and floor 10 feet square determine size of studs spaced 2 feet 0 inch on center with no additional bracing.
Solution:

   (1) Equivalent diameter of bin=10 feet or $4\left(\dfrac{\text{floor area}}{\text{floor perimeter}}\right)$.

   (2) Enter chart (fig. 4). Find intersection of bin depth 10 feet and bin diameter 10 feet. Read bending moment
       =1,620 foot-pounds for 1 foot 0 inch spacing.
       =3,240 foot-pounds for 2 feet 0 inch spacing.

(3) Assume allowable flexural stress=1,800 pounds per square inch. Enter chart (fig. 5) at bending moment=3,240 foot-pounds and run line to 1,800 pounds per square inch on fiber-stress scale. Read section modulus=22 inches ^{3}.

(4) Assume 2-inch dressed material for studs (actual width 1.625 inches). On chart (fig. 5) extend line from 1.625 inches on scale for width of rectangular beam through 22 inches ^{3} on scale for section modulus to scale for depth of rectangular beam and read depth=9.0 inches. Studs 2 by 10 inches would be required. This is much larger than normally used for wall construction.

Problem 2.—For same bin and stud spacing in problem 1 determine stud size when intermediate cross ties are used.

Solution:

(1) Take bending moment for simple loading=3,240 foot-pounds as before.

(2) Assume tie height above floor=6 feet 6 inches.
Ratio: $\frac{\text{tie height}}{\text{wall height}}=0.65$.

(3) Enter upper right diagram of chart (fig. 4) at above ratio and read across to intersection with M_{tie} curve for ratio: $\frac{\text{bin height}}{\text{bin diameter}}=0.5$ which most nearly corresponds to the actual condition, or interpolate. At above intersection read ratio: $\frac{\text{maximum moment with tie}}{\text{maximum moment without tie}}=0.36$ approximately. Bending moment at tie=0.36(3,240)=1,166 foot-pounds approximately.

(4) Check positive moment below tie. Proceed as above and read from M_B curve, ratio: $\frac{\text{maximum moment with tie}}{\text{maximum moment without tie}}=0.4$ approximately. Bending moment below tie=0.4(3,240)=1,296 foot-pounds approximately.

(5) Check positive moment above tie. Proceed as above and note that negative moment at tie continues as negative moment to top of stud.

(6) Maximum moment (1,296 foot-pounds) occurs below tie. Using this value enter chart (fig. 5) and, proceeding as in problem 1, solve for depth of 2-inch stud using same fiber stress=5+ inches. With ties 6 feet 6 inches above floor use 2- by 6-inch studs spaced 2 feet 0 inch on center.

Problem 3.—For the same bin dimensions and stud spacing in problem 1, determine reactions in studs.

Solution:

(1) Enter chart (fig. 3). Find intersection of bin depth 10 feet and bin diameter 10 feet.
Read total lateral pressure
=1,260 pounds approximately for 1-foot 0-inch spacing.
=2,520 pounds approximately for 2-foot 0-inch spacing.

(2) Ratio: $\frac{\text{bin height}}{\text{bin diameter}}=1$.

15

(3) Enter upper right diagram of chart (fig. 3) using ratio: $\dfrac{\text{bin height}}{\text{bin diameter}} = 0.5$ which most nearly corresponds to the actual condition, or interpolate.

Read ratio: $\dfrac{\text{reaction in rib}}{\text{total lateral pressure}}$

$= 0.35$ approximately, at top of rib (no tie).

$= 0.65$ approximately, at bottom of rib (no tie).

Reaction at top of stud $= 0.35(2,520) = 882$ pounds approximately.

Reaction at bottom of stud $= 0.65(2,520) = 1,638$ pounds approximately.

Maximum reaction (and shear) $= 1,638$ pounds.

Design top and bottom connections or top and bottom ties as desired for these loadings.

(4) Check unit shear. $v = \dfrac{3V}{2bd} = \dfrac{3(1,638)}{2(1.625)(9.5)} = 159$ pounds per square inch.

Problem 4.—For the same bin dimensions, stud spacing, and cross-tie position in problem 2, determine reactions and shears.

Solution:

(1) Take total lateral pressure for simple loading $=2,520$ pounds as before,

also ratio: $\dfrac{\text{tie height}}{\text{wall height}} = 0.65$ and ratio: $\dfrac{\text{bin height}}{\text{bin diameter}} = 0.5$ used in problem 2.

(2) Enter upper right diagram of chart (fig. 3) and read ratio: $\dfrac{\text{reaction in rib}}{\text{total lateral pressure}}$

$= -0.08$ approximately, at top of rib.

$= 0.42$ approximately, at bottom of rib.

$= 0.66$ approximately, at tie.

And ratio: $\dfrac{\text{shear in rib}}{\text{total lateral pressure}}$

$= 0.22$ approximately, at top of tie.

$= 0.44$ approximately, at bottom of tie.

Negative reaction at top of stud $= -0.08(2,520) = 202$ pounds approximately.

Positive reaction at bottom of stud $= 0.42(2,520) = 1,058$ pounds.

Positive reaction at tie $= 0.66(2,520) = 1,663$ pounds.

Shear at top of tie $= 0.22(2,520) = 554$ pounds.

Shear at bottom of tie $= 0.44(2,520) = 1,109$ pounds.

(3) Check unit shear $v = \dfrac{3(1,109)}{2(1.625)(5.625)} = 182$ pounds per square inch.

This is excessive, and lower placement of tie should be tried.

Problem 5.—For the bin used in problem 1, determine size of joist across a 10-foot simple span. Joist spacing 2 feet 0 inch on centers.

Solution:

(1) Enter chart (fig. 2, A). Find intersection of bin depth 10 feet and bin diameter 10 feet. Read unit vertical pressure

on floor=445 pounds per square foot or approximately 450 pounds per square foot, including dead load.

(2) Enter chart (fig. 5). Connect point 450 pounds per square foot with 24-inch spacing of joists and locate intersection with working line. From this point extend line through 10-foot span and find simple beam bending moment for uniformly distributed load=11,250 foot-pounds. Since the load distribution is uniformly increasing to the center of the span, construct triangle extending from this point (11,250 foot-pounds) to the moment coefficient line 0.167 and read on original scale bending moment=15,000 foot-pounds.

(3) If the joists receive adequate lateral support from bridging and bracing by the flooring, the maximum allowable unit fiber stress in bending for the selected kind and grade of timber may be used without reduction. Assuming this is 1,800 pounds per square inch, extend line from this point on fiber-stress scale of chart (fig. 5) to 15,000 foot-pounds on bending-moment scale. Read section modulus=100 inches[3].

(4) Assume 3-inch dressed material for joists (actual width 2.5-inches). On chart (fig. 5) extend line from 2.5 inches on scale for width of rectangular beam through 100 inches[3] on scale for section modulus to scale for depth of rectangular beam and read depth=15.5 inches. Joists 3 inches by 16 inches would be required.

(5) Check for horizontal shear.

$$v = \frac{3V}{2bd} = \frac{3\left(\dfrac{9,000}{2}\right)}{2\ (2.5)\ (15.5)} = 174 \text{ pounds per square inch.}$$

A similar check can be made for this type of loading on a simple rectangular beam by reference to the allowable fiber stress in bending where

$$v = \frac{3fd\,(\text{inch})}{4L\,(\text{inch})} = \frac{3\ (1,800)\ (15.5)}{4\ (10 \times 12)} = 174 \text{ pounds per square inch.}$$

Problem 6.—For the same bin and joist spacing in problem 5 determine size of joists if they are continuous over two 5-foot spans.

Solution:

(1) Determine maximum simple beam moment by entering chart (fig. 5) at 450 pounds per square foot and connecting this point with 24-inch spacing of joists to locate intersection with working line. From this point extend line through 5-foot span and read simple beam bending moment=2,800 foot-pounds approximately. For practical purposes the coefficients shown in chart (fig. 5) for uniformly loaded continuous beams can be used. For a beam continuous over 2 equal spans the maximum-moment coefficient=−0.125 at the center support, therefore the bending moment for a simple beam (2,800 foot-pounds) applies.

(2) Assuming allowable fiber stress of 1,800 pounds per square inch, extend line from this point on the fiber-stress scale to 2,800 foot-pounds on the bending-moment scale and read section modulus=18 inches[3] approximately.

(3) If 2-inch dressed material (1.625 inches actual width) is used, extend line from this point on width of beam scale through 18 inches [3] on section modulus scale and read 8.4 inches on depth of beam scale. Joists 2 by 10 inches would be required.

(4) Check unit shear.
Maximum shear (see table in Note A below) $=0.625\,wl=0.625$ (900 pounds per foot span) (5 feet) $=2,812.5$ pounds.

$$v=\frac{3V}{2bd}=\frac{3(2,812.5)}{2(1.625)(9.5)}=\frac{8,437.5}{30.875}=273.2 \text{ pounds per square}$$

inch, which is excessive.

(5) Check unit horizontal shear for 3- by 10-inch joist,

$$v=\frac{3(2,812.5)}{2(2.5)(9.5)}=177.6 \text{ pounds per square inch.}$$

This may be considered close enough to the permissible unit longitudinal shearing stress (175 pounds per square inch), and the minimum joist size required will be 3 by 10 inches.

(6) Check required bearing area for 3- by 10-inch joist at maximum reaction. If allowable unit stress in bearing across grain is 400 pounds per square inch and the maximum reaction (see table in Note A below) $=1.25\,wl=5,625$ pounds (where $w=900$ pounds per foot span and span $l=5$ feet), required bearing area $=\dfrac{5,625}{400}=14.06$ square inches at middle support.

For the 3- by 10-inch joist the bearing area should be $\dfrac{14.06}{2.5}=5.6$ inches long.

NOTES ON BEAM AND GIRDER DESIGN

Note A.—In proportioning beams for the heavy loads and short spans that normally occur in grain bins, the safe unit stresses in horizontal shear and in bearing across grain are often the critical factors rather than the safe unit stress in bending. For beams that are continuous over equal spans, uniform loading may be assumed. This permits use of the following coefficients of wl (where $w=$ load per foot of span l) to determine total reaction and maximum shear at each support. Coefficients above line are used for total reaction and those below line for maximum shear. Span numbers in parentheses.

$$\frac{0.375}{.375}(1)\frac{1.25}{.625}(2)\frac{0.375}{.375}$$

$$\frac{0.400}{.400}(1)\frac{1.10}{.600}(2)\frac{1.10}{.600}(3)\frac{0.400}{.400}$$

$$\frac{0.393}{.393}(1)\frac{1.142}{.607}(2)\frac{0.929}{.464}(3)\frac{1.142}{.607}(4)\frac{0.393}{.393}$$

$$\frac{0.395}{.395}(1)\frac{1.131}{.605}(2)\frac{0.974}{.500}(3)\frac{0.974}{.500}(4)\frac{1.131}{.605}(5)\frac{0.395}{.395}$$

$$\frac{0.394}{.394}(1)\frac{1.134}{.605}(2)\frac{0.962}{.490}(3)\frac{1.019}{.510}(4)\frac{0.962}{.490}(5)\frac{1.134}{.605}(6)\frac{0.394}{.394}$$

$$\frac{0.394}{.394}(1)\frac{1.133}{.605}(2)\frac{0.965}{.493}(3)\frac{1.007}{.507}(4)\frac{1.007}{.507}(5)\frac{0.965}{.493}(6)\frac{1.133}{.605}(7)\frac{0.394}{.394}$$

18

For example, to estimate maximum unit horizontal shear of beam continuous over 4 equal spans, find maximum shear=0.607 (wl).

Unit horizontal shear $v = \dfrac{3}{2} \dfrac{\text{maximum shear}}{bd}$

To estimate area required in cross bearing at same support, find total reaction=1.142 (wl). Bearing area required=

$$\frac{\text{total reaction}}{\text{allowable unit stress across grain}}$$

Note B.—It is assumed that the influence of lateral support for beams will be taken into consideration. Floor joists are braced by the flooring and also by bridging on spans over 8 feet. Wood girders are usually braced by joists nailed to them. Studs are laterally supported by sheathing and, in some deep bins, are supported at every 6 feet or less of height by bridging or by 1 by 6 ribbons beveled on top and nailed to the inside face of studs.

In many cases, however, beams are not braced laterally; for example, a wood joist resting on a steel beam to which it is not firmly attached. In such cases the working stress should be reduced in selecting a beam to resist the bending moment. Various formulas have been recommended by different authorities to derive reduction factors for this purpose. The following values are suggested (where l=laterally unsupported span of beam in inches and b=breadth of beam or beam flange in inches):

l/b ratio:	Reduction factors for laterally unsupported steel beams
15	1.00
20	.92
25	.835
30	.75
35	.669
40	.596

For example, if the allowable maximum stress in a laterally supported steel beam is 20,000 pounds per square inch, the stress in a beam with an l/b ratio of 30 should not exceed 75 percent thereof, or 15,000 pounds per square inch.

It should be noted, however, that these reduction factors do not allow for the effect of shape or form of the beam. For more accurate determination of the reduction in allowable load or unit stress for beams of various sections without lateral support refer to the equations given in Wood Handbook, by the United States Department of Agriculture, or the charted values in the fifth edition of Steel Construction; a Manual for Architects, Engineers and Fabricators of Buildings and Other Steel Structures, by the American Institute of Steel Construction.
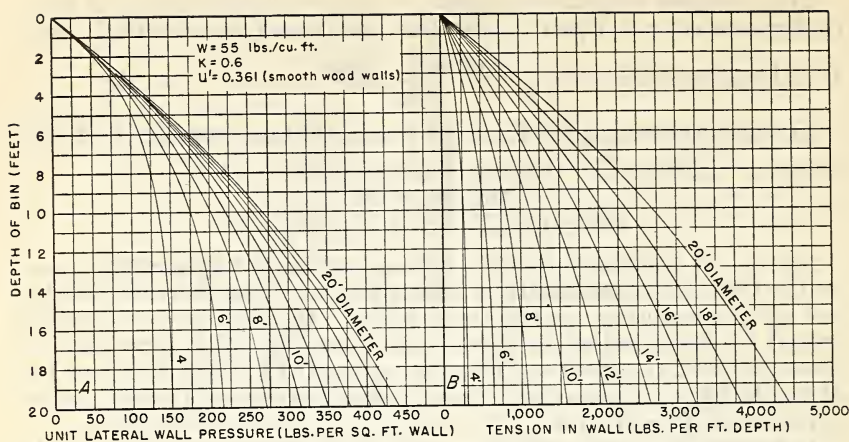
FIGURE 1.—Lateral loads in cylindrical grain bins and rectangular bins of equivalent diameter: *A*, Unit lateral wall pressure (pounds per square foot); *B*, wall tension in cylindrical bins (pounds per foot depth).
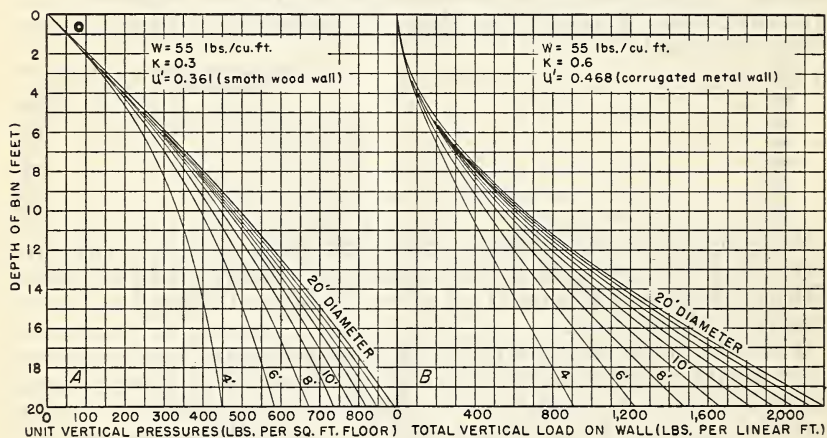

FIGURE 2.—Vertical loads in cylindrical grain bins and rectangular bins of equivalent diameter: *A*. Floor loads (pounds per square foot); *B*, vertical wall loads (pounds per linear foot).
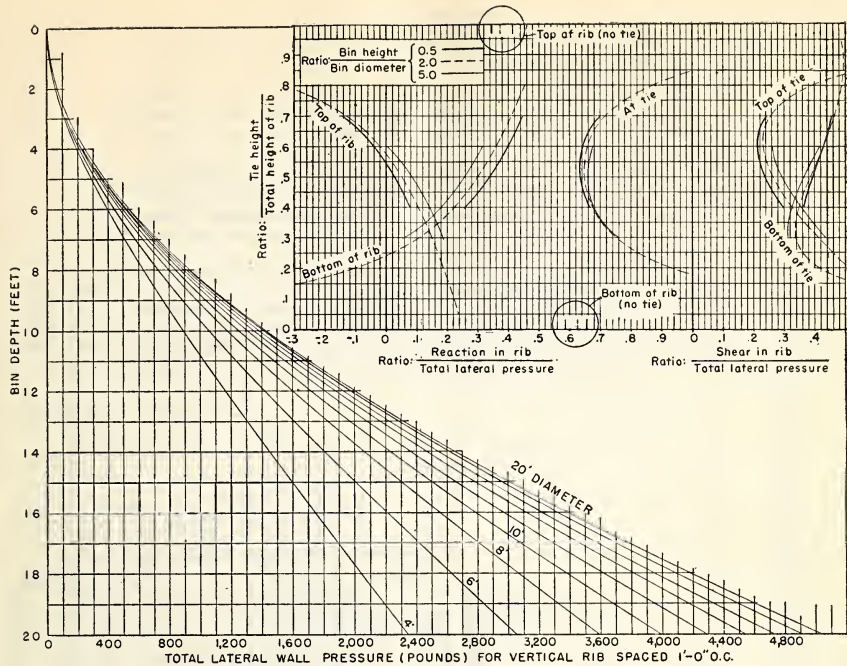
FIGURE 3.—Total loads, reactions, and shears for vertical wall ribs (studs) with and without wall ties.
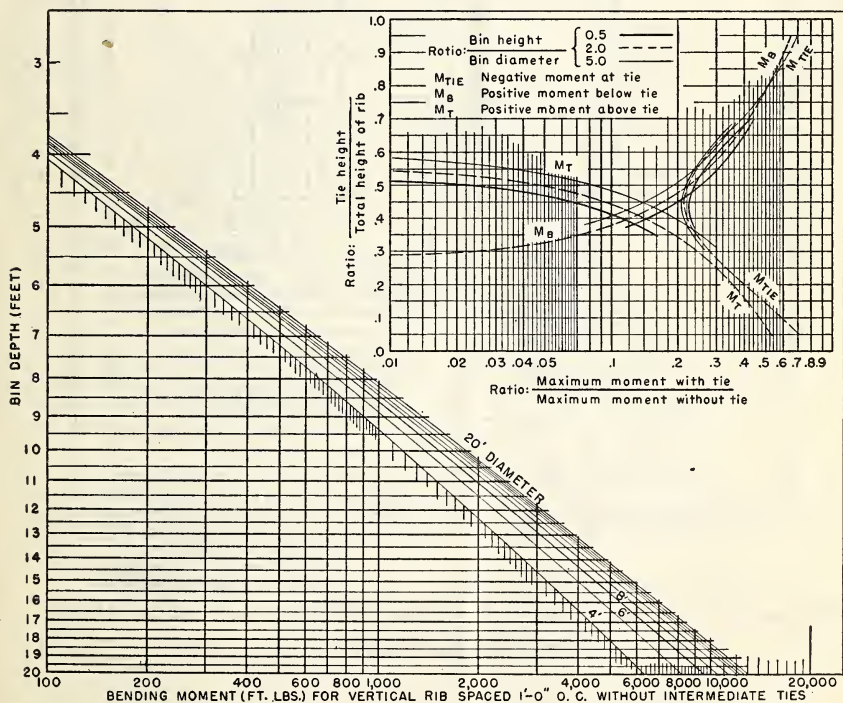

FIGURE 4.—Bending moments in vertical wall ribs (studs) with and without wall ties.

21

EXAMPLES:

Problem 1. *Determine size of wood joists required to carry 150 lbs. per sq. ft. (live plus dead load) across an 18' simple span. Joist spacing 16" o.c. Allowable fibre stress 1,800 lbs. per sq. in.*

With straight edge join point a (150 lbs. per sq. ft.) with b (16" joist spacing) to locate point c on working line. Join point c with d (18' span) and read bending moment at point e (8,100 ft. lbs.) Join point e with f (1,800 lbs. per sq. in) and read section modulus at point g (54 in³).

Assume 3" nominal joist width. Extend line from h (2.625" actual joist width) through point g and read required depth of joist at point k (11.2"). Use 3"x12" joists.

Problem 2. *Determine section modulus of wide flanged steel girders required to carry the floor in problem 1. Girders are 18' o.c. and are continuous over three 20' spans. Allowable fibre stress 20,000 lbs. per sq. in.*

By same method used in problem 1 join points a, m, n, and p to find simple beam bending moment at point q (135,000 ft. lbs.)

From diagram below note maximum moment coefficient for a beam continuous over 3 equal spans = -.100 at both interior supports. Construct triangle q, r, s, (see explanation below) and read maximum moment at point s (108,000 ft. lbs.) Join points s and t (20,000 lbs. per sq. in.) and read section modulus at point u (64 in³).
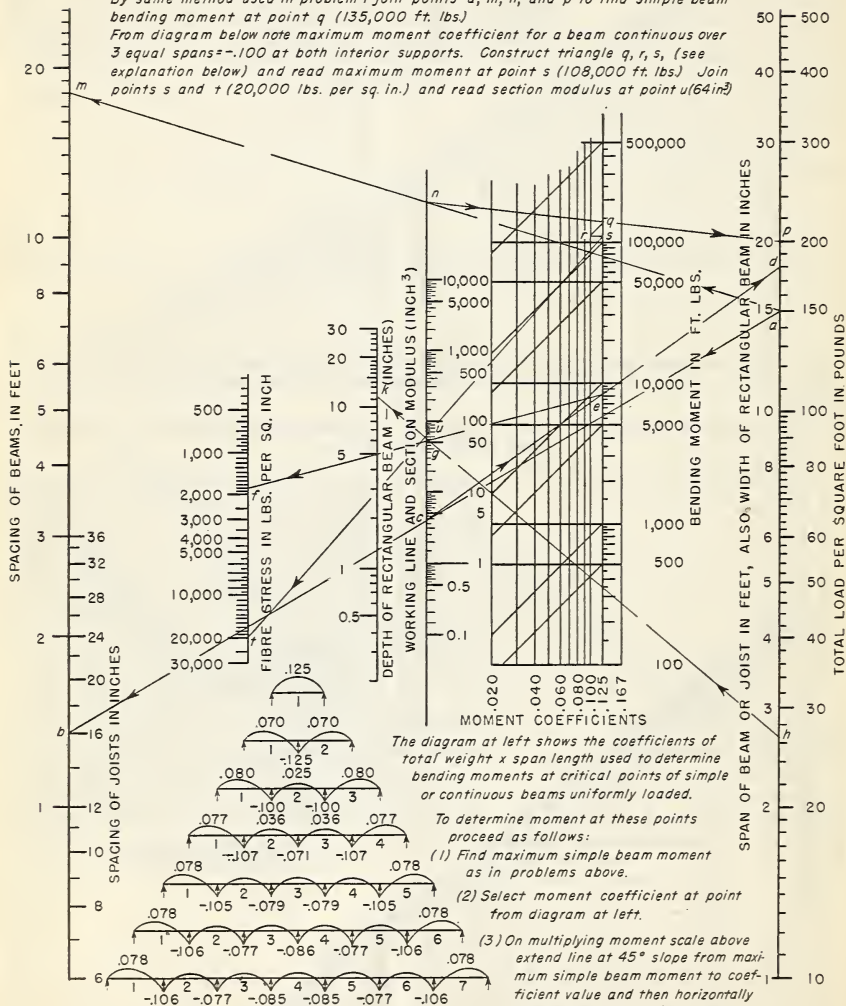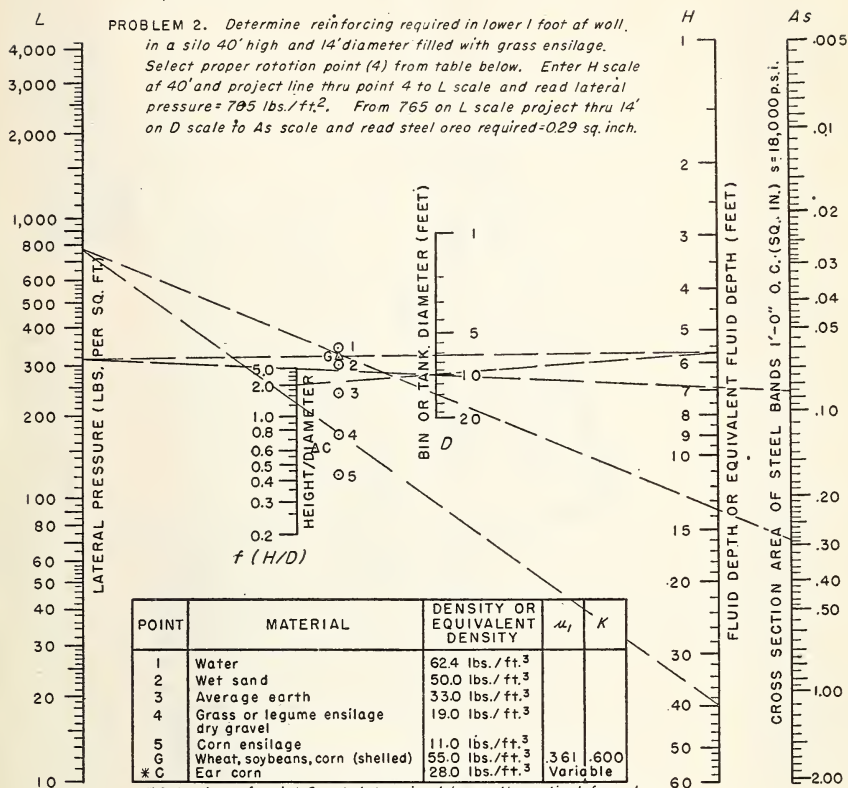
UNIFORMLY LOADED SIMPLE BEAMS OR CONTINUOUS BEAMS WITH EQUAL SPANS

FIGURE 5.—Beam or girder design.

22

PROBLEM 1. *Determine reinforcing required in lower 1 foot of wall in a bin 20' high, 10' diameter filled with wheat. Calculate H/D = 20/10 = 2. Enter f(H/D) scale at 2, project line thru 10' on D scale to H scale. Read value of equivalent fluid depth = 5.67'. From table below select proper rotation point for wheat (G). Project from 5.67' on H scale thru point G to L scale and read value of lateral pressure = 316 lbs./ft.². From 316 on L scale project thru 10' on D scale to As scale and read steel area required = 0.086 sq. inch.*

PROBLEM 2. *Determine reinforcing required in lower 1 foot of wall in a silo 40' high and 14' diameter filled with grass ensilage. Select proper rotation point (4) from table below. Enter H scale at 40' and project line thru point 4 to L scale and read lateral pressure = 765 lbs./ft.². From 765 on L scale project thru 14' on D scale to As scale and read steel area required = 0.29 sq. inch.*

POINT	MATERIAL	DENSITY OR EQUIVALENT DENSITY	μ_1	K
1	Water	62.4 lbs./ft.³		
2	Wet sand	50.0 lbs./ft.³		
3	Average earth	33.0 lbs./ft.³		
4	Grass or legume ensilage dry gravel	19.0 lbs./ft.³		
5	Corn ensilage	11.0 lbs./ft.³		
G	Wheat, soybeans, corn (shelled)	55.0 lbs./ft.³	.361	.600
*C	Ear corn	28.0 lbs./ft.³	Variable	

Selection. at point C not determined by mathematical formula. Its use gives values for lateral pressures closely approximating available test values.

Grain and ear corn pressures determined by Janssen's formula $L = \frac{wR}{\mu_1}(1-e^{\frac{-K\mu_1 H}{R}}) = \frac{wD}{4\mu_1}(1-e^{\frac{-4K\mu_1 H}{D}})$ in cylindrical tanks or bins where L = lateral pressure in lbs./ft.², w = density of grain in lbs./ft.³, D = bin diameter in feet, K = ratio of lateral to vertical pressure, μ_1 = coefficient of friction of grain on wall, and H = height of fill in feet. See problem 1 above for example of grain bin or corn crib design.

Water, sand, earth, gravel and ensilage pressures determined by fluid pressure formula $L = w_a H$ where L and H are defined as above and w_a = the density of a fluid which would give lateral pressures equal to those exerted by the fill material. See problem 2 above for an example of the design of cylindrical tanks or bins for these materials.

FIGURE 6.—Steel reinforcing required for cylindrical storages.